Design and Analysis of Li-fi Underwater Wireless Communication System

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***Abstract*—Efficient exploration of techniques for underwater communication is still needed to reduce energy consumption, transmission losses and should also provide high speed communication. This paper presents a simple yet high speed communication system based on visible light communication, also recognised as light fidelity (Li-fi), for underwater applications. The concept of Li-fi for use in underwater wireless communication is borrowed from a novel approach presented by Dr Harald Haas of Germany to improve data transfer and information security for in air applications. This paper presents basic design of a Li-Fi underwater communication system and novel concepts that can help to reduce the overall power consumption. Simulation and comparative study is also given in the paper to provide useful insight of this new technology.**

***Index Terms*—Li-fi, Signal recovery, LED, Frequency Modulation, Pulse Width Modulation, Communication**

I. Introduction

Because of the ongoing expansion of maritime activities such as environmental monitoring, oceanographic data collection, offshore oil field exploration, port security, and tactical surveillance, there has been an increase in demand for high-speed underwater wireless communications [1]. Under water acoustics still has many limitations which need to be enhanced, like capacity, efficiency, availability and security [2], [3], [4], [5], [6]. For various underwater applications such as imaging and real time video transmission, optical wireless communication (OWC) also known as Li-fi has been introduced as a high-capacity, low-latency alternative. Li-fi could be used effectively to solve these existing limitations. In this technology, visible light, explicitly from LED's, is used for communication purposes instead of regular incandescent bulbs. Because the capacity of regular incandescent bulbs to cope with sudden changes in forward current is not good in comparison with LED's and light appears to be continuous all the time, even for very sensitive sensors. LED is a good candidate to be used in this means of communication, because their response to sudden shifts in voltage is very quick [7]. LED is set *ON* when a 1 (high voltage) passes through it and *OFF* when a logic 0 (low voltage) passes through it. A photo-diode detects the digital signal and communication takes place accordingly. Different researchers are doing work on this technology worldwide and they claim that this technology has potential to send digital data at about 10 Gbps [8]. Electromagnetic band spectrum has different types of frequency bands that are used by humans for different purposes. For example, the microwaves are used in mobile services and telephones, infrared is used for communication but with limited intensity because it is dangerous for human eyes otherwise. X rays are used in hospitals for diagnosis purpose. Moreover, the visible spectrum can also be used for the purpose of underwater communication shown in Fig.1. Inspiration of this technology came from a remote control of a television, as it sends bits of digital data to television [9], [10].

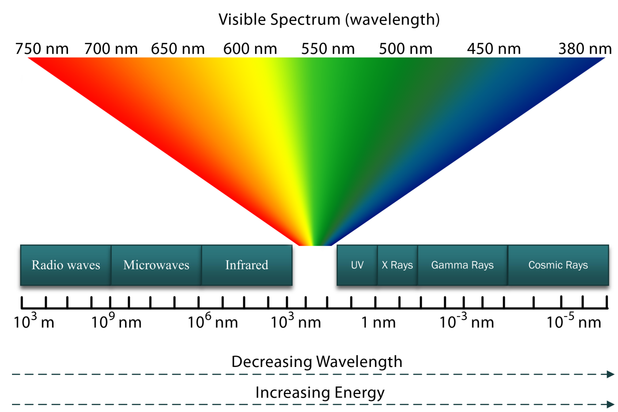

Fig. 1: Electromagnetic spectrum.

The main contributions of this paper are:

- Use of frequency modulation (FM) scheme to make the signal more secure by making it a band pass signal.
- Use of pulse width modulation (PWM) technique to control the dimming sequence of LED driving circuitry.
- Design of a multiple LED driving circuitry to transmit the communicating digital signal.

Moreover, the design of Li-fi system also enjoys the benefit of low cost over acoustic communication, as it just consists of a bunch of LED's and photodiodes.

The remaining of the paper is structured as follows. In Section II, design of the proposed model is examined. In Section II-A proposed modulation scheme for the system is examined. In Section II-B, a dimming sequence for led drive circuitry is briefly described and a working model is also examined. In Section II-C, led drive circuitry is analysed and a multiple led system as a drive circuitry is also examined. In Section III, effect of noise in Li-fi communication is assessed. Section IV conclude the paper.

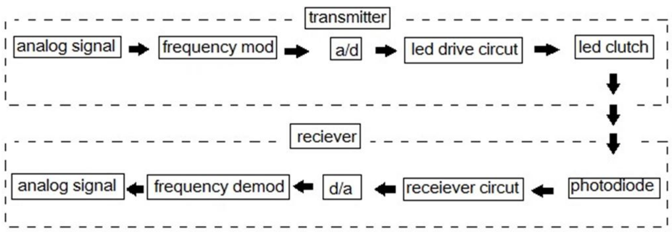

Fig. 2: A simple communication li-fi system design

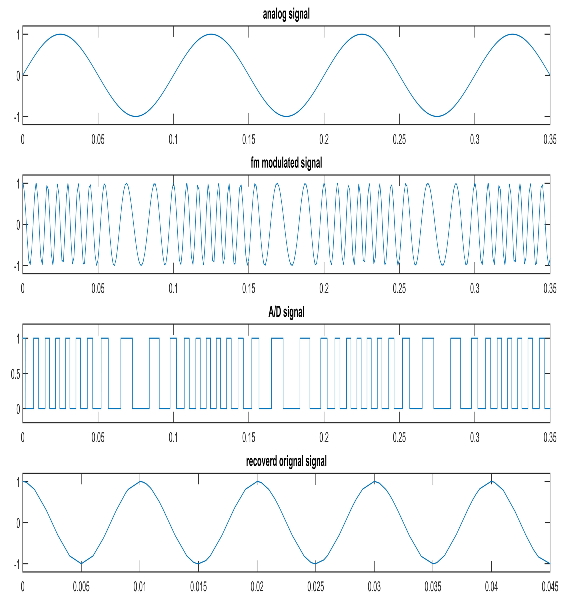

Fig. 3: Waveforms of the transmitted signal, modulated signal, A/D signal, and the recovered signal.

II. Design of Proposed System

In this section the proposed Li-fi communication system shown in Fig 2 is presented. The system is modelled/analysed using Matlab/Simulink. A simple analog signal is applied on the input of the transmitter. After this the signal is fed into modulation block.

A. Frequency Modulation Block

Researchers use different modulation schemes such as orthogonal frequency division multiplexing (OFDM), sub carrier index modulation ofdm (SIM-OFDM) and phse shift keying (PSK) [11], [12], [13]. Modulation of the signal basically helps it to remain in original condition even if some kind of noise came through. The above mentioned modulation schemes are a bit complicated to apply and they make the hardware of the system more expensive, we use Frequency Modulation (FM) in our system as it is very simple and inexpensive when deployed on hardware level. From here the signal will be fed to PWM block.

B. PWM as a Dimming Sequence

A dimming sequence is also designed to dim the light brightness to a minimum level where it gets almost negligible, yet still able to communicate between Tx/Rx. For this purpose PWM technology is used and it has been observed that when the duty cycle is cut up to 10% the communication still takes place perfectly but lower than 10%. Communication is affected to such extent that the signal can not be recovered anymore. The main reason to use a dimming sequence is to make it more power efficient by controlling the duty cycle of the applied power. From there the signal is fed to the driving circuitry.

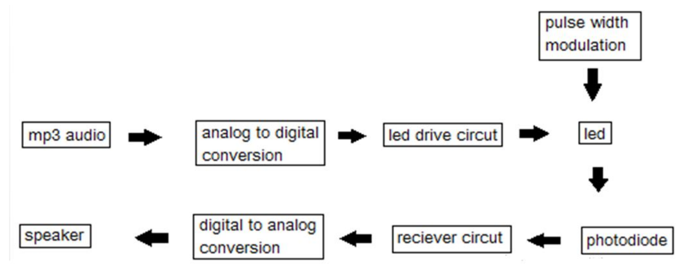

Fig. 4: Dimming circuit block diagram

C. LED Driving Circuit

LED driving circuit is the key part of this technology. It consists of a high frequency low-power transistor that gets the digital signal. This circuit is mounted after ADC block under the water. This part of Li-fi can itself be a research area which is controlling the forward changing current/voltage in an efficient way. It may be noted that different LED color combination Like RGB (red green brown) may be used to get the best communication results. In Li-fi system, LED's of different colors can be used to send some specific data. A simple LED drive circuit is drawn in Fig 5. As a single LED transmits a limited amount of data, a multi-LEDs driving circuitry is an essential requirement to achieve larger data transfer rates (like Gb/s). A multiple LED's driving circuitry is demonstrated/examined in Fig 6 for this purpose.

D. Receiver Block

Receiver block consist of a photo diode that converts the digital signal from LED driving circuitry into an electrical signal. The signal then moves to digital to analog converter (DAC). After that demodulation block and in the end we get our signal back.

III. Results and Analysis

A. Noise Model Analysis

When the digital signal is transmitted through water, ideally it is received at the receiver without any noise/distortion and no recovery signal or filters are required but it's not possible. There are different kinds of noises present in water through which the signal moves, like noise from sunlight in the day time which is known as ambient noise, effect of distance on luminance power, and noise due to reflection from different surfaces. In Fig 7, a general model is shown which is used to

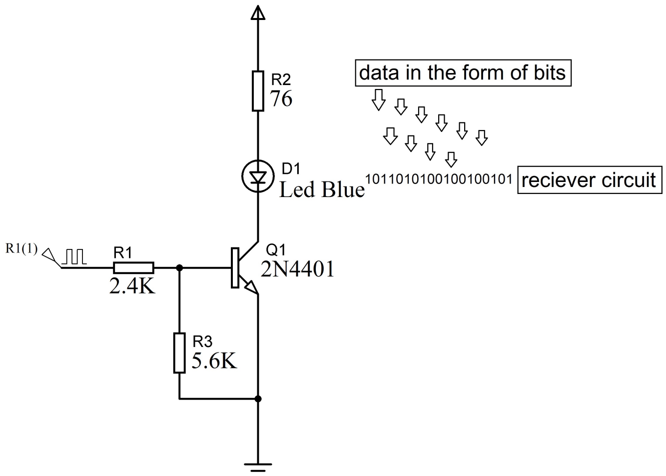

Fig. 5: LED drive circuitry.

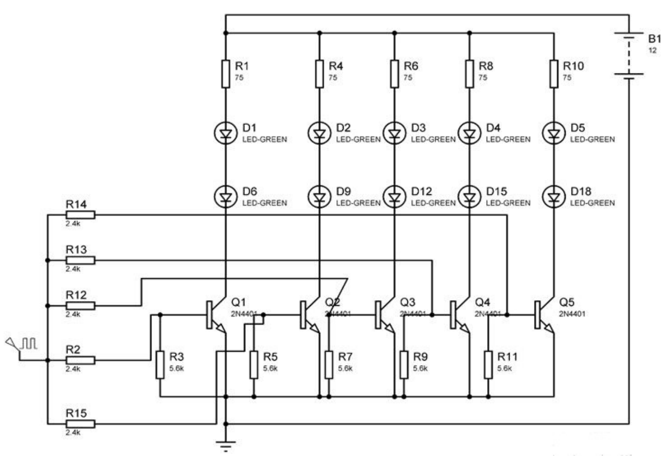

Fig. 6: Multiple LED drive circuitry.

simulate the effect of noise on the signal and its recovery. In this system, a Bernoulli generator is used to generate digital random signal with probability of the zero at 0.5 initial seed 3 and a sampling time of 0.5 sec. Random noise with lower bound of 0.2 and upper bound 1 is added, sampling time for it is kept at 1/10. Later the noise added signal is fed to a low-pass FIR filter. The equiripple design method is used in the filter to smooth out noise that is added in the digital signal. The output is a digital signal that is sent through communication medium that is water. Noise considered to see the effect of distortion bound limit in the signals shown in Fig 8 is a random noise. Shift in the received signal is the effect of the filter. When the digital signal is recovered it can be amplified if needed.

B. Lambert's Cosine Law

While using Li-fi for underwater communication, the phenomenon of reflection and refraction is quite dominant. The light spreading after reflecting/refracting from the surfaces has a lambertian effect. Lambert cosine law lets us understand that the light scattered from the light sources is having a cosine reliance on the angle of emission with respect to the surface normal. In other words, we can say that this rule gives us the illuminance of light on a screen/surface due to point source in any direction. Suppose we have a source LED that has a luminous intensity L in all directions, the equation for that is given below.

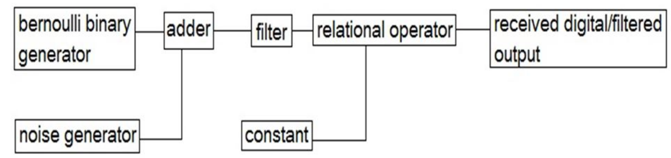

Fig. 7: Model to visualize noise effect and signal regeneration.

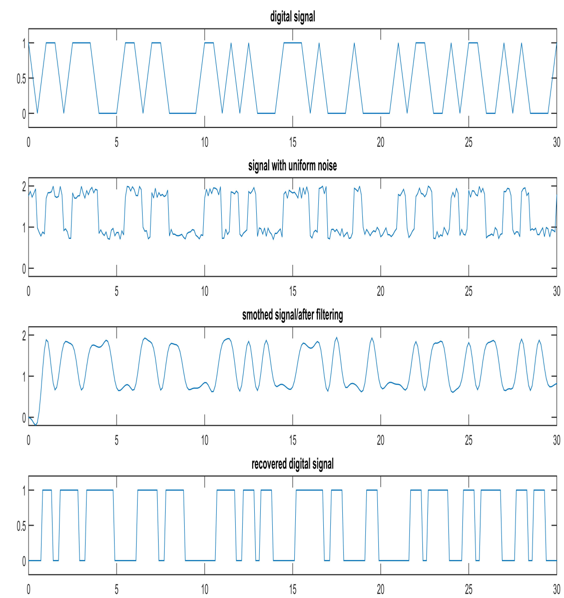

Fig. 8: Recovered digital signal.

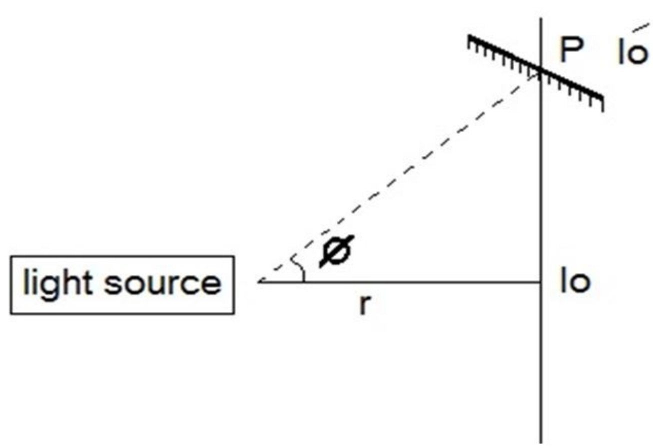

Fig. 9: Showing the luminous intensity according to the angle made with normal.

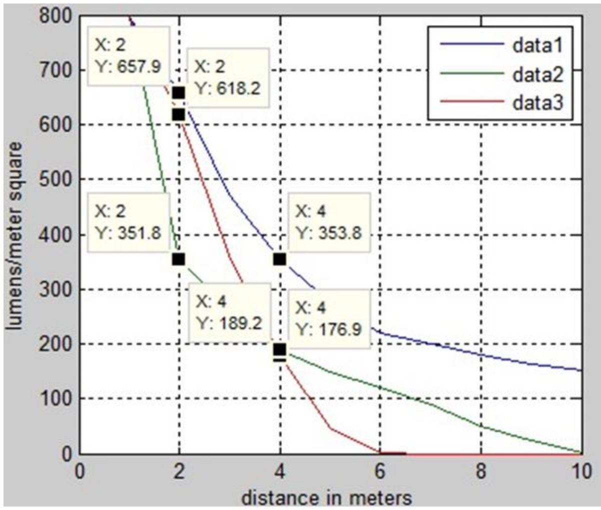

Fig. 10: Graphical presentation of lambert cosine law

$$L = \phi/4\pi \tag{1}$$

In equation (1), L is the luminous intensity in all directions and ϕ is the luminous flux of the source in all directions uniformly.

$$I_0 = L/r^2 \tag{2}$$

In equation (2), I_0 is a point that is normal to the source. At that point, the luminous intensity can be determined by the equation (2). Here, L is the luminous intensity in all directions and r is the distance of the source of light from the surface on which it is falling

$$I_0^{'} = Lcos\phi/r^2. \tag{3}$$

But if light from the source falls on point P, it must be having some angle. The luminous intensity at that point is computed by the equation (3). In equation (3) L is the luminous intensity in all directions, ϕ is the angle with which the light from the source is falling on the surface. $I_0^{'}$ is the maximum luminous intensity on point P due to the source. We have taken three values of ϕ for calculation (25^0, 50^0, and 75^0) and with it eventually the distance from the light source is also increased. So from the results of the $I_0^{'}$ we can see that the lumens/watt are reducing as the angle of source and the surface is increasing. It proves that in this technology, communication through light also calls to give importance for the line of sight.

C. Lambert's Cosine Law Graphical Explanation

From Fig.10, we can conclude the following.

- The data 1 is the output in which we move the receiving device away from the digital LED data transmitting device, while at the same time maintaining the viewing angle and only increasing the receiving distance.
- The data 2 is the output in which we move the receiving device away from the digital LED data transmitting device, but not retaining the line of sight, which also causes some degree of shift, while at the same time increasing the distance.
- The data 3 output in which we do not move the receiving device away from the digital LED data transmitting device, which means not increasing the distance but only simply shifting 25^0 angles at each step, which means not maintaining the line of sight but maintaining the distance.

IV. Conclusion

The work presented in this paper mainly relies on simulation work, however, it can still be analyzed from Fig 7. That noise is having quite an effect on Li-fi communication underwater. With the addition of various noises experimentally, we observed that as the sample per area of noise increases, the signal starts to become noisy. The second result concluded from Fig 8 is that if bound of the noise is between 1 and 0.7, any kind of noisy signal can be retrieved. But if noise bound increase and goes between 1 and 0.2, signal starts to be noisy and information will be lost. There are a lot of opportunities/scenarios in which this technology can be deployed. As this technology is still in improvement stages, thus its full capabilities have yet to be revealed to the rest of the world. This technology will act as a hot-spot for the wireless access underwater. This technology will be a step towards greener environment. And humans will be able to achieve large communication data rates through it.

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